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DECAY ASYMMETRIES OF CHARGED SIGMA HYPERONS*

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It was pointed out by T. D. Lee, et al.[1] that since parity need not be conserved in the decay of sigma hyperons, the decay could proceed via both L = 0 and L = 1 angular momentum states. If a beam of transversely polarized sigmas were available, then the distribution of decay pion with respect to the direction of polarization would follow a $1 + \alpha P \cos\theta$ law in the center of mass. In our experiment P is the average value of the polarization over all production angles and over all available initial state energies due to the deuteron internal momentum distribution and α, the asymmetry parameter, is a measure of parity non-conservation. α is defined by

$$\alpha = \frac{2\,\mathrm{Re}\,(S^*P)}{S^2 + P^2}$$

The asymmetry parameters for reactions $\Sigma^+ \rightarrow \pi^+ + n$, $\Sigma^+ \rightarrow \pi^o + p$, and $\Sigma^- \rightarrow \pi^- + n$ are denoted by α^+, α^o, and α^- respectively.

D'Espagnat[2] has shown from PC invariance and the $|\vec{\Delta} I| = \frac{1}{2}$ rule, together with the experimentally known π-nucleon phase shifts, the branching ratio of $\Sigma^+ \rightarrow \pi^+ + n / \Sigma^+ \rightarrow \pi^o + p$ and ratio of lifetimes $\tau_{\Sigma^+} / \tau_{\Sigma^-}$ that

$$\sin^{-1}\alpha^+ = \cos^{-1}\alpha^o = -\sin^{-1}\alpha^-.$$

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Cool[3] and collaborators have studied the interaction

$$\pi^+ + p \rightarrow \Sigma^+ + K^+$$
$$\Sigma^+ \rightarrow \pi^+ + n$$
$$\rightarrow \pi^o + p$$

at an incoming pion momentum of 1.13 Bev/c. They found the sigmas polarized perpendicularly to the production plane and found $\alpha^+ P = .03 \pm .05$ and $\alpha^o P = .75 \pm .17$. From this they concluded that $\alpha^+ \approx 0$ and $\alpha^o \approx 1$. The only attempt, heretofore, to measure α^- was reported by Franzini[4] et al. They studied the reaction $\pi^- + d \rightarrow \Sigma^- + K^o + p$ at incoming pion momenta of 1.23 Bev/c. This reaction in the impulse approximation is simply $\pi^- + n \quad \Sigma^- + K^o$, and this is charge symmetric to Cool's reaction. Therefore, they assert, their sigmas are polarized, and their finding of $\alpha^- \overline{P} = .01 \pm .17$ implies $\alpha^- \approx 0$. This experiment leaves two questions open. First, might not final state interactions between the Σ and proton wash out polarization? Second, this experiment is at a pion momentum 100 Mev/c higher than that of Cool's. Therefore, polarization might be appreciably smaller. In fact, Baltay[5] et al., report $P \leq .25 \pm .2$ for the reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$ at 1.23 Bev/c incoming pion momentum.

This experiment consists of two parts, in each of which we study the complete set of αP. First we shall consider the reactions

$$\pi^+ + d \rightarrow \Sigma^+ + K^+ + n$$
$$\Sigma^+ \rightarrow \pi^+ + n$$
$$\rightarrow \pi^o + p$$
$$\pi^- + d \rightarrow \Sigma^- + K^o + p$$
$$\Sigma^- \rightarrow \pi^- + n.$$

The production reactions are charge symmetric and at the same energy. If any final state interactions occur, they too are charge symmetric so that P is the same for the two production reactions. If then we find $\alpha^{o}P \neq 0$, we can conclude $P \neq 0$ and obtain the upper limit for α^{-}.

The same experiment was also done independently with another set of charge symmetric reactions:

$$\pi^{+} + d \rightarrow \Sigma^{+} + K^{o} + p$$
$$\Sigma^{+} \rightarrow \pi^{+} + n$$
$$\rightarrow \pi^{o} + p$$
$$\pi^{-} + d \rightarrow \Sigma^{-} + K^{+} + n$$
$$\Sigma^{-} \rightarrow \pi^{-} + n$$

with similar results.

The 72" Alvarez bubble chamber filled with liquid deuterium was exposed to separated pion beams at the Bevatron in November, 1960, and May, 1961. In total, 42,000 π^{+} and 34,200 π^{-} pictures were taken, of which 18,750 π^{+} and 17,330 π^{-} have been processed to date and are reported here.

All the film was scanned twice for any event which resembled one of the eight topologically possible representations of sigma production and decay. Of these, six were kinematically analyzable. Our efficiency for the two scans was 97.3 %. All the candidates were examined by a physicist. If the event satisfied fiducial volume, sigma and K^{o} length criteria, the physicist prepared a sketch for the event, picking the two optimum views for measuring each track. These events were then measured with a digitized microscope. The events were then processed through the Berkeley PANG-KICK-EXAMIN programs.

The events that fitted one or more of our hypotheses were re-examined on the scanning table by two physicists. For events with a unique fit, all tracks had to have ionization compatible with fitted momenta. Those which fitted more than one hypothesis were similarly identified by ionization.

Of the approximately 2,500 events measured, 421 were found to fit one of our event types and satisfy our acceptance criteria.[6] Of these, 122 were of the type $\pi^{+} + d \rightarrow \Sigma^{+} + K^{+} + n$, 67 of $\pi^{+} + d \rightarrow \Sigma^{+} + K^{o} + p$, 152 of $\pi^{-} + d \rightarrow \Sigma^{-} + K^{+} + n$, and 80 of $\pi^{-} + d \rightarrow \Sigma^{+} + K^{o} + p$.

A complete discussion of cross-sections, the impulse model, and systematics is given in a separate report.[7]

The mean pion momentum at interaction is 1192 Mev/c and the distribution has a half width at half maximum of 46 Mev/c. Thus, on the average our energy is approximately midway between the energies where Cool reports very large and that where Baltay reports very little polarization. The lack of polarization at 1230 Mev/c was explained by Baltay to be due to a substantial amount of D-wave interaction present as evidenced by their differential cross-section. Our differential cross-sections show no prevalance of D-waves.[8]

For the accepted events the decay angle with respect to $\vec{p}_{\pi} \times \vec{p}_{\Sigma}$ direction in the center of mass of the sigma was calculated using the equation

$$\cos\theta = \frac{(\vec{p}_{\pi} \times \vec{p}_{\Sigma}) \cdot \vec{p}_{d}}{|\vec{p}_{\pi} \times \vec{p}_{\Sigma}|\, p_{d}^{cm}}$$

where p_{π} is laboratory momentum of incoming pion, p_{d} is laboratory momentum of decay pion, and p_{d}^{cm} is the momentum of decay pion in

the sigma center of mass. For each distribution we made a linear chi-squared fit. From these, we deduced the αP's to be:

for reactions

$$\pi^+ + d \rightarrow \Sigma^+ + K^+ + n$$

$$\Sigma^+ \rightarrow \pi^+ + n: \quad \alpha^+\overline{P} = .03 \pm .23 \quad (\chi^2 = 3.6)$$

$$\Sigma^- \rightarrow \pi^o + p: \quad \alpha^o\overline{P} = .61 \pm .29 \quad (\chi^2 = 7.9)$$

$$\pi^- + d \rightarrow \Sigma^- + K^o + p$$

$$\Sigma^- \rightarrow \pi^- + n: \quad \alpha^-\overline{P} = .27 \pm .22 \quad (\chi^2 = 5.0)$$

and reactions

$$\pi^+ + d \rightarrow \Sigma^+ + K^o + p$$

$$\Sigma^+ \rightarrow \pi^+ + n: \quad \alpha^+\overline{P} = -.12 \pm .30 \quad (\chi^2 = 10.2)$$

$$\Sigma^+ \rightarrow \pi^o + p: \quad \alpha^o\overline{P} = -.52 \pm .41 \quad (\chi^2 = 13.1)$$

$$\pi^- + d \rightarrow \Sigma^- + K^+ + p$$

$$\Sigma^- \rightarrow \pi^- + n: \quad \alpha^-\overline{P} = .17 \pm .16 \quad (\chi^2 = 5.6)$$

where the expectation value for χ^2 is 8.0.

Our results, therefore, are in agreement with known values of α^+ and α^o and we find α^- consistent with zero as expected.

It is interesting to note that within our limited statistics $\overline{P}$ for the reaction $\pi^+ + d \rightarrow \Sigma^+ + K^o + p$ is negative. In the impulse approximation this reaction is simply $\pi^+ + n \rightarrow \Sigma^+ + K^o$ which is charge symmetric to $\pi^- + p \rightarrow \Sigma^- + K^+$. Therefore, we can deduce that for this latter reaction $\overline{P} \approx -.52 \pm .41$. Again, $\overline{P}$ represents an average polarization over all production angles and all initial state energies in the π^+-d reaction. Michel[9] has pointed out that if the triangle inequality

$$\sqrt{2\sigma^o} \leq \sqrt{\sigma^+} + \sqrt{\sigma^-}$$

is in fact an equality, then the polarizations for reactions

$$\pi^+ + p \rightarrow \Sigma^+ + K^+$$

$$\pi^- + p \rightarrow \Sigma^o + K^o$$

$$\pi^- + p \rightarrow \Sigma^- + K^+$$

should all have the same sign and magnitude. The results, above, show that we find approximately the same magnitude but opposite signs. On the other hand, we find that our differential cross-sections $\frac{d\sigma^+}{d\Omega}$, $\frac{d\sigma^-}{d\Omega}$ do not depart significantly from equality when compared to known values of $\frac{d\sigma^o}{d\Omega}$. (11)

References and Explanatory Notes

(1) Lee, T. D., Steinberger, J., Feinberg, G., Kabir, P. K., and Yang, C. N., Phys. Rev. 106, 1367 (1957).

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(5) Baltay, C., et al., Rev. Mod. Phys. 33, 374 (1961).

(6) Minimum length for K^o's was 2 mm and maximum length for sigmas was three lifetimes.

(7) Kraemer, R. W., Ph. D. Dissertation, Johns Hopkins University, 1962. (Also accompanying paper).

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(11) Kraemer, R. W., op. cit.